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# TECHNICAL
# MEMORANDUM

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| Chronicles as a Regenerative Recording, | SYSTEM |
| System Testing, and Analysis Concept | DEVELOPMENT |
| for SAGE and Other Real-Time Digital Systems | CORPORATION |
| by | 2500 COLORADO AVE. |
| H. Sackman | SANTA MONICA |
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SDC

CHRONICLES AS A REGENERATIVE RECORDING, SYSTEM TESTING,

AND ANALYSIS CONCEPT FOR SAGE AND OTHER REAL-TIME DIGITAL SYSTEMS

by

H. Sackman

1.  SUMMARY

Chronicles is introduced as an experimental recording vehicle which can re-
generate an original computer test run in its entirety by playing back all the
recorded inputs into the operational program.   Although the playback notion is
ancient history, the successful practical application of total system playback
is recent and new for complex systems such as SAGE.   Chronicles recording in
SAGE emerged from an experimental DCA Model 8 design to its present experimental
status in Model 9.   Current  applications of Chronicles in five SAGE studies
are reviewed, demonstrating its versatility and some of the problems encountered
in controlled system tests and exploratory investigations.

A comparison with other SAGE recording vehicles indicates that Chronicles increases the usefulness of conventional recording and makes possible entirely new types of recording. Some possibilities for its extended use in SAGE are suggested for military, training, and programming applications.

Methodological advantages and disadvantages of the regenerative recording concept are summed up for man-machine digital systems operating in real time. In general, Chronicles adds the ability to remember, completely reconstruct, and rigorously manipulate past digital system events. The major disadvantages lie in possible program design problems applied to some computer systems and in uneconomical use of Chronicles for certain types of tests for which it is not suited.

The overall utility of a regenerative recording capability appears to be sufficiently important to be considered as an essential element in real-time systems as contrasted with the traditional view of recording as a secondary support function. The Chronicles capability is suggested as an integral part of the original design and life-cycle for man-machine digital systems.

2.  INTRODUCTION

This report is concerned with a new recording concept in SAGE called Chronicles, employed for the first time in the multi-division frame time field tests (4). This is an experimental SAGE DCA recording system which permits complete regeneration of all computer events as they occurred in referent computer runs. This paper develops the basic position that the regenerative concept, as contrasted with conventional partial recording techniques, is a powerful tool not only for SAGE but also for other large-scale digital systems operating in real time.

Conventional SAGE recording vehicles such as MORT (Master Operational Recording Tape) and ATRS (Assembly Test Recording System) used for operational and program testing purposes, respectively, are essentially partial or selective recording schemes. Only portions of program inputs or program outputs are recorded. There is no capability for reconstructing and rerunning the entire digital system test run with partial recording. The referent test is lost unless the complete set of program inputs is available in a suitable form for a computer rerun.

Chronicles first records permanent core to establish initial conditions, and then records all system inputs during a given test run. The rerun mode uses the recording tape as input to the SAGE computer program. First, it reconstructs permanent core tables just as they were immediately before the first subframe of the initial point selected for the rerun. Then, the recorded input tables are reset for each successive subframe as in the original computer operation. The resulting computer run follows the same steps in the same sequence as they occurred in the original test.

Figure 1 is a simplified schematization of Chronicles. The first row shows the basic digital system flow of inputs-program-outputs. The second row provides examples of these three basic digital system components for SAGE. The third row shows direct playback of the referent computer run. The fourth row indicates that experimental modifications of Chronicles inputs, or modifications of the program system, or both, result in mutations of the original program outputs.
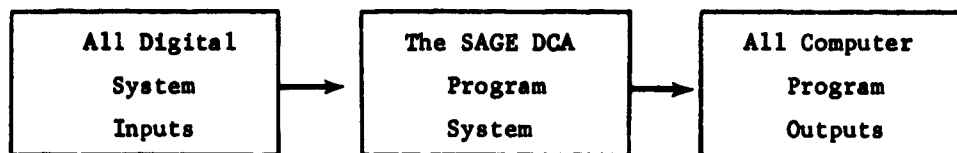
3. A HISTORY OF CHRONICLES RECORDING IN SAGE

Playback recording is not new in principle but has been difficult to achieve
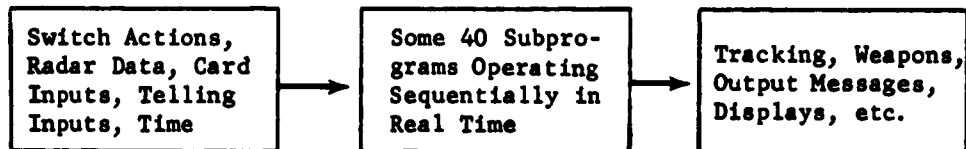
FIGURE 1

SCHEMATIC REPRESENTATION OF CHRONICLES FOR DIRECT PLAYBACK
AND MUTATIONS OF ORIGINAL DIGITAL SYSTEM EVENTS

I.  DIGITAL SYSTEM FLOW

| All Digital System Inputs | → | The SAGE DCA Program System | → | All Computer Program Outputs |

II.  REPRESENTATIVE EXAMPLES

| Switch Actions, Radar Data, Card Inputs, Telling Inputs, Time | → | Some 40 Subprograms Operating Sequentially in Real Time | → | Tracking, Weapons, Output Messages, Displays, etc. |

III.  CHRONICLES REPRODUCTION OF ORIGINAL DIGITAL SYSTEM EVENTS

| Records Contents of Permanent Core Initially and All System Inputs Thereafter | → | Original Chronicles Inputs are Rerun through the Same Program System | → | Chronicles Rerun Results in the Same Computer Program Outputs |
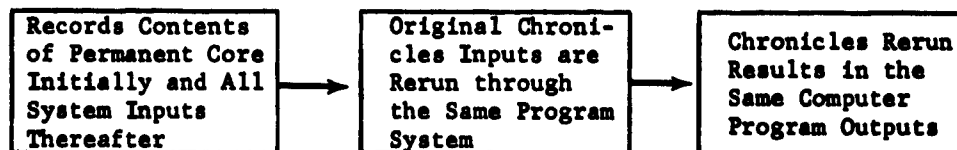
IV.  CHRONICLES MUTATIONS OF ORIGINAL DIGITAL SYSTEM EVENTS

| Experimentally Modified Chronicles System Inputs | → | Experimentally Modified Program System | → | Experimentally Induced Mutation of Original Computer Program Outputs |
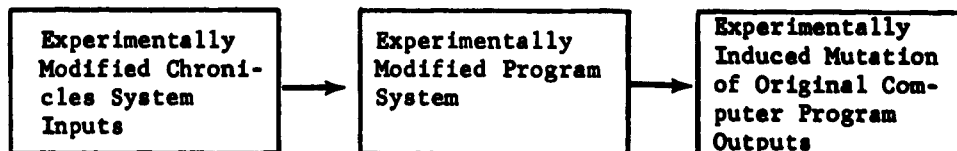
in practice for complex systems such as SAGE. The earliest documented work toward this goal appeared in 1960 in the development of SAVDAT (Save Input Data) by Black (1). This program recorded a portion of the inputs of a live run so that related parts of the original run could be played back in non-real-time.

The development of the capability for complete playback came in 1961 with Munson's design of the Chronicles recording program in connection with live multi-division tests of SAGE frame time and associated system capacity (4). The program was christened "Chronicles" since its output is a replication of original computer events in the same sequence in which they occurred.

For SAGE, the complete set of system inputs to the computer consists of: switch actions, radar data, card inputs, telling inputs, and time, up to a maximum of approximately 10,000 words per subframe which occurs roughly every five seconds. This tape storage rate results in filling up about one to two tapes per hour depending upon system load levels.

By overlapping tape transfer with central computer operation, Chronicles recording time added only 2% to total computer operating time. Tape transfer in the FSQ-7 computer requires 325 microseconds per word. The transfer instruction requires only 6 microseconds per word. With efficient overlap between tape transfer and central computer operation, only 6/325 or 2% of additional computer operating time is added to the operational system. Efficient overlapping of central computer operation and tape transfer is a critical requirement for the Chronicles technique. It should not significantly increase computer operating time to the point where undesirable effects are introduced in live runs due to the recording process itself.

Chronicles recordings were successfully taken in nine SAGE Direction Centers for the multi-division frame time tests. Subsequent developmental work on the experimental version of Chronicles for Model 9 has eliminated some limitations of the original program used in Model 8.

a. Instead of using a deck to start Chronicles recording, a switch action at the Air Surveillance Officer's console will initiate recording.

b. Chronicles has a new feature which will permit selection of multiples of 10-minute intervals of the recording for reruns up to a maximum of 60 minutes to avoid cycling through data which is not of interest to the investigator. Skipping uninteresting segments does not affect the quality of the rerun.

c. Chronicles has been made compatible with other SAGE recording programs such as MORT and ATRS.

The experimental version of Model 9 Chronicles occupies 290 registers of drum storage and 529 words of core storage. Technical programming details of the original experimental Model 8 version of Chronicles are described by Sackman and Munson (4) with updated information on the Model 9 version by Toche and Houston (7, 8, 9, 10).

One remaining problem has not yet been fully solved. All time inputs are not recorded due to difficult accessibility. This results in slight timing variations in the rerun mode as compared to the original test.

4. COMPARISON OF CHRONICLES, MORT, AND ATRS RECORDING IN SAGE

A comparison of Chronicles with the two most frequently used recording

systems will point up the major differences and the supportive relationships
among these three systems. Table 1 schematizes the three recording systems.
The first row indicates the general purpose of each recording system. The second
row shows that Chronicles is the only recording system capable of playing back
the original complete set of computer events in its rerun mode. The third row
contrasts the relatively negligible recording time of Chronicles relative to
the other systems. For purposes of more direct comparison, ATRS recording time
for all or nearly all program inputs would be higher than that for Chronicles
since tape transfer time does not overlap as efficiently with central computer
operating time as it does with Chronicles. The fourth row shows comparative
drum and core storage in the Model 9 base. Note the relative storage economy
for Chronicles.

The fifth row shows comparative recording content. Chronicles has one
recording mode. MORT has three standard recording modes. ATRS has numerous
recording modes and could record much more or much less than the other two
systems at the option of the programmer. Th s comparison points up the dependency
of Chronicles on the other two systems.

As a direct recording system Chronicles records all program inputs. An
investigator interested in the analysis of, say, radar inputs or switch actions
could strip these inputs from the Chronicles tape without a full-scale computer
rerun of the original test.

## TABLE 1

### A COMPARISON OF CHRONICLES, MORT, AND ATRS RECORDING IN SAGE

|   | | Chronicles | MORT | ATRS |
|---|---|---|---|---|
| 1. | Purpose | General | Operational | Program Testing, Training Evaluation |
| 2. | Playback Capability | Yes | No | No |
| 3. | Recording Time | Up to .35 Seconds Per Frame | *Up to 3 Seconds Per Frame | Variable, and High |
| 4. | Model 9 Register Storage | Drums - 290<br>Core - 529 | Drums - 981<br>Core - 7682 | Drums - 399<br>Core - 1753 |
| 5. | Recording Content | All Program Inputs, Periodic Permanent Core Content | Primarily Tracking and Weapons History | Very Flexible, Practically All Inputs and Outputs |
| 6. | Associated Data Reduction Systems | Some Special Purpose Processors | RUN, GIANT | GIANT, Synoptic Processors, GRATIS |

*Highest observed CMR (Master Recording subprogram) operating time in the multi-division frame time test, recorded at the Chicago Sector (4, p. 274).

If program outputs are desired, it is necessary to operate Chronicles in its rerun mode and use an additional special recording system to extract the desired data. Depending on the output data desired, either MORT, ATRS, or a special program might be the most efficient to use. Although Chronicles makes it possible to record any program outputs after the referent test run, it does not have the capability for recording such outputs and must be supplemented by some output-recording program. ATRS is especially flexible for this purpose. The three programs thus supplement one another in that MORT or ATRS may record outputs in conjunction with a Chronicles rerun.

The supportive relationship between the three programs is borne out further in the last row of Table 1 listing the associated data-reduction systems. Except for some highly specialized processors used in some experimental studies, Chronicles has no associated data-reduction system. MORT and ATRS have extensive, general-purpose processors such as RUN and GIANT. If the investigator knows exactly what he wants and can get it directly with MORT-RUN, or ATRS-GIANT, he does not need a Chronicles recording unless he also wants a permanent record of the test.

If the test data and test analysis are primarily unpredictable, Chronicles recording provides the investigator with complete flexibility in analyzing any part of the test run with whatever technique he may choose based on test feedback. This means he can see what the test is like before deciding which data he wants to analyze. Then he can iterate the entire procedure with new Chronicles reruns. In the event neither MORT nor ATRS satisfy test recording requirements, a special selective recording and associated data-reduction system

must be taken from other available sources or specifically made for the given test.

## 5.  CURRENT APPLICATIONS OF CHRONICLES IN EXPERIMENTAL SAGE STUDIES

The Chronicles recordings of the live multi-division frame time tests are currently being used as the data base for five experimental studies.  A brief description of the applications will indicate some of the advantages and limitations of Chronicles for experimentation with digital systems.

In one study, Chronicles tapes of Model 8 frame time for a test sector is compared against Model 9 frame time (5).  The test basically consists of running the adapted Model 8 Chronicles tape through the Model 9 program.  The Chronometer recording program was used in conjunction with the Chronicles rerun to measure subprogram and overall operating times.  By holding all factors constant, including an entire air battle involving over 6000 switch actions taken by military operators, and varying only the DCA Program Model, a rigorous comparison of frame time may be made.

Consider the experimental precision made possible in this case by the Chronicles recordings.  With traditional experimental techniques, it would be necessary to go back to the field, use the same test problem with the same crew at the same sector, and conduct the test with the Model 9 instead of the Model 8 SAGE program.  Even in the best of all possible experimental worlds there would be uncontrollable changes in the test problem, the crew, and the operational sector which would generate uncontrolled error variance in the results. With Chronicles, at least in theory, essentially all variables remain constant except the independent variable.

Stated statistically, the standard error of the experimentally measured mean difference in Model 8 vs. Model 9 frame time tends to approach zero because of the high correlation between the original test run and the experimental test rerun. The formula for the standard error is equal to:

$$\sqrt{s_1^2 + s_2^2 - 2r_{12}\,s_1\,s_2}\;.$$

In the ideal limit, the experimental control afforded by Chronicles reruns tends to approach the condition in which $s_1 = s_2$, and $r_{12} = 1.00$, which results in a limiting standard error of zero. This is simply another way of saying that if the experimental controls are perfect, the observed experimental differences are "true" differences with no associated error variance. Chronicles replications, permit, at least in principle, an approximation of this ideal controlled experiment in a manner almost impossible in traditional experimental techniques for certain types of experiments.

In actual practice, however, the programming leap from Model 8 to Model 9 was very difficult. It was not possible to adapt the Model 8 Chronicles tape to run in the Model 9 computer program as smoothly as in the original live test run in the Model 8 program. Switch alarms increased and interceptor tracking quality was poorer in the experimental test rerun. The Model 9 master tape which was used had numerous errors and changes during the testing period. A later version had fewer errors. Changes in switch interpretation, air sur-veillance, simulation, and in the Chronometer processor were required for an acceptable experimental rerun.

Valid frame time comparisons may still be made between Model 8 and Model 9,
but the experimental error variance does not approach the ideal condition de-
scribed above. An important practical limitation in the use of Chronicles
experimental reruns in an altered program system lies in the expense of the pro-
gramming effort required to achieve satisfactory compatibility with Chronicles
inputs. It should be pointed out that the extra cost of the additional programming
effort still fell far short of the total expense involved in returning to the
field for a live frame time test for Model 9.

In a second experiment the same Chronicles test tapes are used to compare
the effectiveness of three switch processing systems including the current and
two experimental switch systems (5). In this experiment, total system inputs
and most of the operational program are held constant with the exception of the
switch and display processing portion of the program which constitutes the in-
dependent variable. The primary performance measure derived from the study is
essentially the comparative speed of the three switch processing systems in
providing display responses to switch requests as measured by the Chronometer
recording program used in the Chronicles rerun mode. Here too, programming
problems have been encountered in achieving a successful experimental run.
Since the tests have not been completed, the difficulties are not known. They
appear to be problems in handling simulated inputs and timing information.

The preceding two studies represent critical experimental tests of explicit
operational hypotheses. They point up the practical constraints of experimental
mutations of the original test run by altering inputs, the program system, or
both. The following three investigations are examples of exploratory, normative
experimental studies using the Chronicles vehicle.

The third study consists of processing all the switch actions taken by military operators during the multi-division frame time test (5). The data constitute a sample of approximately 50,000 console actions. They provide the basis for establishing a variety of switch action frequency norms for types of switch actions by type of operational console derived from a credible wartime setting. They also provide a quantitative basis for comparative measures of operator efficiency under stress.

Without the Chronicles recordings, the test data would have been lost at the completion of the live test. With Chronicles recordings it is possible to select the data which have critical value for the investigator which he was not aware of until he studied the test results. In this case, the switch processing function turned out to be especially critical. This permits the investigator to take advantage of hindsight in his analysis of experimental results.

For this study it was not necessary to rerun Chronicles through the DCA system since the switch actions were already recorded as part of the inputs. The Chronicles switch inputs, where processed by two programs, SWITCH and Stool Pigeon, to obtain the desired measurements. With regard to input data, Chronicles acts as a general-purpose recording vehicle permitting direct retrieval of any part of such inputs.

Another portion of this study involved the tabulation and analysis of alarms in response to incorrect operator actions. This was accomplished by rerunning the original Model 8 Chronicles tape through the Model 8 operational program for the Duluth sector and recording all alarms by means of the NEWPIT program. This rerun was extremely close to but not identical with the original

live run. No notable problems were encountered in the use of Chronicles to peel off the 50,000 switch actions, nor in obtaining operator alarms. The associated cost was very low, essentially amounting to computer rerun time.

In the fourth study the object is to explore variations in crosstell load and associated telling capacity from a normative analysis of crosstell inputs and outputs, and from an examination of associated tracking tables. These will be derived from direct Chronicles playback of the multi-division frame time test tapes (3).

The fifth and most recent study involves dynamic instruction counting to develop statistical norms of how frequently single instructions and certain strings of instructions empirically occur in the SAGE DCA program. The data are derived from a Chronicles rerun of the Duluth sector from available multi-division frame time test tapes. No difficulties were encountered in the play-back run. This study is part of the Command Control Economics research project in the Command Systems Department. Project documentation is not yet available for this study.

The five examples above show the capability of Chronicles as an economical omnibus experimental vehicle for a variety of investigations derived from a single field test effort. They also show the need for updating the Chronicles test tape libraries for new program models, and indicate some types of costly programming adaptation problems in developing satisfactory test reruns.

6. **POSSIBLE UTILITY OF CHRONICLES IN SAGE**

Possible applications of Chronicles to SAGE are sketched under three head-ings: military operations, training, and programming. No systematic study has

been made on feasibility, cost, or on a comparison with alternative approaches
in accomplishing the goals listed.  The uses cited below are suggestive.

## 6.1  POSSIBLE MILITARY APPLICATIONS

6.1.1  <u>Analysis of Live Military Exercises</u>.  The annual country-wide SAC-ADC
exercises such as SKY SHIELD and the periodic Tac-Eval (Tactical-Evaluation)
exercises, often include important and sometimes unexpected results which are
not adequately covered by current manual and automatic partial recording schemes.
Under current recording procedures, computer events falling outside the coverage
of fixed-recording schemes such as MORT are lost.  Chronicles recording encompasses
the total set of computer events over the given test period permitting analysis
of any part of the computer operation <u>after the fact</u> when the cognizant military
commander has much more information on what he considers critical.

6.1.2  <u>Analysis of Transition States of Readiness</u>.  One of the vital functions
of SAGE is that of warning prior to the actual or possible outbreak of hostilities.
Unusual concentrations of unknown aircraft, spoofing tactics, problematic false
alarms, "nervous unknowns," and unexpected radar noise patterns are all subjected
to careful analysis by  cognizant  military personnel.  Sometimes critical local
incidents in the air situation may be deemed sufficiently serious to warrant a
more advanced state of readiness, especially for peripheral SAGE sectors.  Under
current recording capability, there may be no automatic record of any portion of
these critical events as they occur in the computer when MORT recording is turned
off.  Moreover, MORT recording may increase computer operating time prohibitively
in an emergency situation, especially with heavy track and radar input loads,

and impede effective military response by slowing down computer cycle time.  If

MORT recording is on, the data recorded is quite limited and does not include

critical information such as correlated and uncorrelated returns on suspicious

tracks or unusual radar patterns.  Finally, there is no possibility of recon-

structing the entire computer operation which occurred during the critical period

to find out, at a later time, "What really happened?"

Continuous Chronicles recording resolves these difficulties.  The increase

in computer operating time is only 2% of total frame time, actually decreases

as the system load increases, and may be ignored for all practical purposes.

The complete critical event is trapped in the Chronicles  record  in its entirety

as far as digital regeneration is concerned.  Military commanders may want to

totally reconstruct and analyze such sensitive air situations.  The capability

to trap surprise events presupposes continuous Chronicles recording.  Recording

expense will vary depending upon the defined cutoff point:   local option, Normal

Readiness, Increased Readiness, or higher states of preparedness.

In the transition from Normal Readiness to any advanced state of readiness,

up to and including hostilities, all the facts concerning SAGE computer processing

of any critical air situation are available with continuous Chronicles recording.

Thus, SAGE Command and Control can have a computer system with essentially

perfect memory (total recording) and perfect recall (total regeneration).  This

may be generalized, in principle, to any computer-based Command and Control system.

6.1.3 Analysis of Actual Hostilities.  In the event of war, Chronicles may be

run continuously at operational sectors during active combat without interfering

with operations.  As mentioned previously, the increase in computer operating

time due to Chronicles is negligible. Complete combat recordings can thus be obtained which may have important intelligence, warning, and tactical value for follow-on hostile strikes. For example, Chronicles will completely record the jamming patterns, penetration tactics, and evasive actions of hostile aircraft, and reflect the interference in communications to and from the Direction Center due to nuclear effects. As in the case for the buildup of states of readiness, the availability of complete computer events possible with Chronicles could provide military decision-makers with a broader base of facts.

6.2  POSSIBLE TRAINING APPLICATIONS

6.2.1  Chronicles Training Library. Recordings of critical live exercises, such as joint SAC-ADC training missions, or Tac-Eval missions, or SSTM's may be rerun in the original or in a modified form as desired for follow-on training exercises. In particular, all the advantages of extremely expensive live air exercises may be inexpensively repeated or varied as often as desired, including live jamming, radar, and maneuver patterns which are often impossible to duplicate even with the most sophisticated simulation techniques currently available.

6.2.2  Crew Debriefing Via Chronicles. Since Chronicles contains all computer events, crew debriefing playback of the training exercise will show the incontrovertible digital facts, eliminating opinion as to computer events. Each operator can sit at his console, see each action he performed in real time, and observe himself as he behaved in a training combat setting. The 10-minute subdivisions of Chronicles recordings makes it possible to rerun only those portions of training exercises of special interest.

### 6.2.3 Semi-Automated System Training and Problem Generation.

Chronicles could conceivably accelerate the development of a kind of programmed system training. Given any training exercise recorded by Chronicles, a rerun in non-real-time with an accessory program system could measure crew and system performance. On the basis of such measurement, a control program system may modify the original test situation to provide greater stress on objectively measured weak points. A new training problem would be produced based on training-performance feedback from the parent training problem, all more or less automatically, depending upon the desired level of human intervention in the construction of the new problem. This new problem would effectively be an experimental Chronicles mutation of the parent training problem. Related training problems based on crew performance feedback may thus be generated and used for training until satisfactory performance levels are achieved. This application of Chronicles is contingent upon the development of satisfactory performance evaluation and problem-construction programming vehicles which are not yet available. This is an example of the amenability of Chronicles to non-real-time manipulation in the rerun mode retaining the integrity of the original run.

## 6.3 POSSIBLE PROGRAMMING APPLICATIONS

### 6.3.1 Program Design Testing.

The case for the use of Chronicles in parameter testing in program design is probably not very strong. For this type of test, programmers usually know what data they want and get it either with special- or general-purpose recording and data-reduction tools such as ATRS and the associated GIANT system.

A stronger case for Chronicles may be made in relation to assembly and system testing. In the "Proceedings of the SDC Symposium on Assembly and System Testing" held in March 1962, the summary stated (6, p. 50):

> Playback features to recreate situations are desirable aids for test problem analysis.

In these tests, it is generally what the programmer does not know, the "bugs" in total program system operation, or, more positively, the empirical level of computer system performance, that is of prime interest. Since these are usually unpredictable entities, the total digital system recording available with Chronicles permits the test investigator to trap all test digital events which he can analyze as he wishes in later reruns. Since the payoff of such testing is an improvement of the program system, the same Chronicles test inputs may be rerun with the modified or improved program. The outputs or performance level of the rerun provides an experimental comparison of great precision against the original test run in which the program error or unsatisfactory performance was initially detected. The comparison of program performance before vs. after program improvement is made with Chronicles in a system context, that is, in a rerun of the complete operational program with the same inputs. This is not possible with the ATRS facility unless the live test is repeated.

The availability of a Chronicles recording capability would permit more flexible, more economical and more diversified program system testing for certain types of tests which are not possible with conventional, fixed recording schemes. In particular, expensive live mission testing at Phoenix, prior to the field installation of the program model, could be recorded and rerun with less expense as often as desired with the original live inputs against alternative or iterative program improvements based on feedback from the live mission.

A Chronicles capability has been suggested as an integral part of a semi-automated system-testing vehicle in a recent committee report on proposed corporate development projects (2). In the context of this proposed vehicle, called SIESTA (Semi-Automated Experimental System Testing Adjunct), the Chronicles portion would permit the accumulation and maintenance of standardized system test tape libraries and permit experimental reruns.

6.3.2 <u>Operational Field Testing</u>. In general, the same advantages accrue to field installation testing of new program models and installation of SAGE Program Changes in existing models as discussed above in connection with system testing. In the "Proceedings of the SDC Symposium on Assembly and System Testing," the section on field testing included the following (6, p. 18):

> ...Most field testing is post facto analysis of suspected malfunctions, and a 'playback' capability, such as provided by combining the dynamic control of MORT recording with the selectivity of ATRS recording, should be extensively employed...

The "playback" described above is the only selective, fixed recording possible with MORT and ATRS. True regenerative playback of the entire referent computer run is possible with a Chronicles capability. The programmer would then be in a better position to take advantage of an ex post facto analysis.

An additional advantage lies in program trouble-shooting arising from problems encountered in live operations. If Chronicles is continuously recording, trouble situations will be recorded in their entirety and may be rerun when needed by the field programmer. The objective record of the total set of original digital events will usually be more valuable than subjective reports or partial recording information. Without Chronicles, the programming difficulty may be

difficult to trace or reproduce and may come back again if enough information is not available for diagnosis and remedial action. With Chronicles, trouble-shooting time and program malfunction should be correspondingly reduced.

## 7. GENERAL UTILITY OF CHRONICLES IN REAL-TIME MAN-MACHINE DIGITAL SYSTEMS

The discussion of Chronicles thus far has been primarily oriented around SAGE. As indicated in the introduction, the overall purpose of this paper is to present the Chronicles concept as a general-purpose recording philosophy for man-machine digital systems operating in real time. The application of Chronicles in the SAGE system may, in many cases, be readily generalized to other command and control digital systems operating in real time. In this section, the case for a generalized Chronicles capability in real-time digital systems is reviewed in relation to methodological considerations for such systems. These are listed under advantages and disadvantages.

### 7.1 ADVANTAGES OF GENERALIZED CHRONICLES RECORDING

7.1.1 **Total Recording.** Chronicles can completely reproduce any computer system run. As such, it logically includes the capability for all other types of specialized recording within itself.

7.1.2 **Efficient Information Retrieval Vehicle.** Chronicles provides a permanent record of a computer run. It also contains the capability of abstracting any portion or combinations of portions of the run, and of iterative selection of such data as often as desired.

7.1.3 **Selective Real-Event Libraries.** Selective libraries of critical or

important real events may be maintained throughout the life-cycle of a given digital system. Anything that happens ("happens" in the sense of being processed by the computer) in the history of a real-time system can be saved for future use. This constitutes a historical real-time digital-system memory under human control.

7.1.4 <u>System Oriented Analysis</u>. Analysis of any portion of Chronicles records may always be related to total computer system operation. With component recording, rigorously controlled system experimentation is very difficult since the complete computer operation cannot be reconstructed and is permanently lost.

7.1.5 <u>Economy in Time and Overall Cost</u>. For those investigations in which replication is satisfactorily accomplished by regenerating the computer system test environment, and if mutations do not involve prohibitive programming expense, Chronicles provides great economy as compared to the traditional experimental procedure of duplicating the entire live test. The cost of computer rerun is usually only a fraction of the cost of a live field test involving men and equipment, and there is a corresponding savings in elapsed time for obtaining the desired experimental replications or variations.

7.1.6 <u>Increase in Experimental Precision</u>. For experiments involving comparisons or modifications of computer inputs or changes in programs, a realistic test situation obtained in the field be held essentially constant, while only the desired changes are systematically tested via Chronicles. In such situations, uncontrolled experimental error may approach negligible proportions, affording unusual precision in the results unobtainable by techniques based on replications of live test situations.

7.1.7 **Non-Real-Time Experimental Versatility.** A useful property of Chronicles is that the recorded inputs are tagged with real-time identifiers. This permits the investigator to delete, modify, or add any program or input changes in a Chronicles rerun in non-real-time and maintain the timing integrity of the original real-time test operations. With traditional recording techniques, such interference in the original test run may generate undesirable effects. With Chronicles the integrity of the referent computer run is maintained with a negligible increase in central computer operating time due to recording. Great flexibility is possible in deliberate distortion in non-real-time reruns without invalidating or losing the true time relationships of the original test data.

7.1.8 **A Generalized Experimental Heuristic.** Chronicles may act as a catalyst accelerating the experimental process. The investigator may take full advantage of hindsight based on the original experimental results to recast the test situation to settle new critical hypotheses from Chronicles reruns. Thus, Chronicles serves as an ex post facto omnibus experimental vehicle. New experimental mutations introduced into reruns of the original test can multiply the final experimental yield by providing numerous systematic variations of the original test.

7.2 DISADVANTAGES OF GENERALIZED CHRONICLES RECORDING

7.2.1 **Technical Design Problems.** In SAGE, it is possible to obtain Chronicles recordings by adding a maximum of only 2% to total computing operating time. In other computer-based systems it may not be possible to overlap central computer operation with tape transfer as efficiently as in SAGE, in which case the increase

in computer operating time for a Chronicles type of recording system may be pro-
hibitive.  Recording all inputs may present an insurmountable design problem
since some of these may be inaccessible or difficult to record.  There may be
additional difficulties in setting up a suitable rerun mode for some systems.

7.2.2  Uneconomical Rerun Time for Closed-End Investigations.  If the investi-
gator knows exactly which data he wants and can record such data directly from
the original test run, and if he has no need to reconstruct the entire computer
system environment at a later time, the most economical approach is direct re-
cording of the desired data during the original test.  This will save him the
expense of a computer rerun of the test if he relied on Chronicles recording
alone in the initial test.

7.2.3  Prohibitive Experimental Variations.  Some desired experimental variations
may involve costly adaptation of the original Chronicles tapes to provide
acceptable inputs for new or revised programs.  Experimental program variations
may also result in unforeseen and uncontrolled changes in the test run which
may invalidate some of the experimental results.  These kinds of problems are
sometimes difficult to assess in advance, and may involve a substantial programming
effort before enough information is available indicating an invalid experiment.
Although certain types of experimental mutation. of original Chronicles test runs
may in principle be possible, the programming effort may be exorbitant.  Current
experience indicates that these risks may be kept within reasonable bounds by
careful preliminary program costing, and, if possible, by the assignment of
programmers with extensive experience in the overall system.

7.2.4 <u>Maintenance Costs</u>.  For an effective Chronicles capability, it is nec-

essary to update the Chronicles program itself and the associated test record-

ing libraries as new program models are introduced.  If there is not a sufficient

volume of system testing, overhead maintenance may be too costly.

## References

1.   Black, A. J.  SAVADAT (Save Input Data).  A Routine to Save Live Input Data
     in Simulator Tape Format.  FN-GS-151, July 22, 1960.

2.   Jacobs, E. H., et al.  Proposed Corporate Deve'opment Projects.  N-19303/000/00,
     November 12, 1962.*

3.   Rosenthal, M. I.  Work Plan-Information-Transfer Development Project.  N-18314,
     May 25, 1962.*

4.   Sackman, H. and Munson, J.  A Study of SAGE Frame Time and System Capacity.
     TM-690/002/00, March 30, 1962.   SECRET.

5.   Sackman, H. and Munson, J.  Proposal for an Omnibus Frame Time Follow-on
     Project.  N-18226/000/01, June 11, 1962.*

6.   Shasberger, W. M. and Shaw, C. J.  Proceedings of the SDC Symposium on Assembly
     and System Testing - Santa Monica, 14 to 16 March 1962.  D-3502, September 5,
     1962.*

7.   Toche, C. E.  Prototype Chronicles Recording System, Part 1:   The Chronicles
     Recording Function.  FN-6713/001/00, September 4, 1962.

8.   Toche, C. E. and Houston, R. E.  Prototype Chronicles Recording System, Part 2:
     New Subroutines in SAGE for Chronicles.  FN-6713/002/00, July 17, 1962.

9.   Toche, C. E.  Prototype Chronicles Recording System, Part 3:   Chronicles Rerun
     Manual.  FN-6713/003/00, August 17, 1962.

10.  Toche, C. E. and Houston, R. E.  Prototype Chronicles Recording System, Part 4:
     Chronicles Tape Split Facility Program.  FN-6713/004/00, July 17, 1962.

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*These documents are internal, unpublished SDC communications and are not
appropriate for release outside the Corporation.

System Development Corporation,
Santa Monica, California
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ANALYSIS CONCEPT FOR SAGE AND OTHER
REAL-TIME DIGITAL SYSTEMS.
Scientific rept., TM-1042/204/00,
by H. Sackman, 15 March 1963, 25p.,
10 refs.

Unclassified report

DESCRIPTORS: Digital Recording Systems.

Identifiers: SAGE

Reports on Chronicles, a new
recording concept in SAGE employed

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for the first time in multi-
division frame time field tests.
Describes Chronicles as an
experimental SAGE DCA recording
system which permits complete
regeneration of all computer
events as they occurr in referent
computer runs. Develops the basic
position that the regenerative
concept, as contrasted with
conventional partial recording
techniques, is a powerful tool
not only for SAGE but also for
other large-scale digital
systems operating in real time.